A FACILITY FOR ASSESSING SUPPRESSION EFFECTIVENESS IN HIGH SPEED TURBULENT FLAMES

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Background

The work described in this paper is part of a larger effort focused on finding alternatives to halon 1301 for application to aircraft engine nacelle and dry bay in-flight fire protection. The engine nacelle encases the compressor, combustor and turbine. Protection is required to eliminate a possible fire resulting from leaking fuel, hydraulic, or lubrication lines. Dry bays refer to closed spaces in the wings and fuselage, inaccessible in flight, and into which fuel could spray and possibly ignite following an equipment malfunction. Alternative chemical compounds are sought which do not create unacceptable safety, environmental, or systems compatibility problems.

Four burner arrangements are being used to rank the relative suppression effectiveness of different gaseous agents: (1) a cup burner similar to the design of Sheinson *et al.* (1989), (2) an opposed flow diffusion flame (OFDF) burner following the technique developed by Seshadri (1977), (3) a turbulent spray flame burner (Grosshandler *et al.*, 1993), and (4) a detonation tube. The detonation tube discussed in this article has been chosen to examine the performance of alternative agents in a highly dynamic situation, in which the residence time of the agent in the reaction zone is an order of magnitude shorter than in the other three burners and in which pressure effects on the chemistry are thought to be important.

Experimental Facility

A high speed turbulent flame can occur when the composition of a combustible mixture falls in an appropriate range and the geometric conditions promote the turbulent mixing process. The speed of the flame front initially will be subsonic (based upon the unburnt gas composition), with a modest pressure wave preceding the reaction zone. If the burnt mixture is confined in space, the flame will accelerate and make a transition to supersonic flow, resulting in a close coupling between the shock wave and flame structure. Given enough distance, the flame will approach its theoretical Chapman-Jouget velocity, with a shock wave propagating supersonically ahead of the reaction zone. Although there exists extensive literature on these mechanisms, understanding of the suppression process in high speed flames is lacking.

An experimental facility has been constructed to produce a high speed turbulent flame in which the suppression performance of alternative agents can be compared. Chapman and Wheeler (1926) first noted that a methane-air flame could be accelerated to a terminal velocity in a shorter distance within a circular tube by placing obstacles into the flow. Lee *et al.* (1986) built on this observation to study quasi-detonations in hydrogen- and hydrocarbon-air mixtures. Although an obstructed flow can be more difficult to analyze than the flow in a smooth-walled detonation tube, the obstructed tube was chosen for the current study to more closely simulate suppression of an actual fire in a dry-bay. The design of the deflagration/detonation tube is based directly upon the work of Peraldi *et al.* (1986). They found that a 50 mm diameter tube with a blockage ratio of 0.43 could be used to create high speed flames and quasi-detonations within the first several meters of an 18 m tube. By varying the equivalence ratio of ethene/air mixtures from 0.5 to 2.1, they were able to produce flame velocities between about 600 and 1300 m/s.

The apparatus in the current study consists of three 2.5 m long sections of 50 mm inside diameter stainless steel tubing. The first two sections constitute the driver portion, and the third the test section, (see Figure 1.) Rods formed into a spiral with a pitch equal to 50 mm are inserted into the tube to produce a blockage ratio equal to 44%. The driver section is equipped at the closed end with a spark plug for igniting the

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combustible mixture. The ignition energy is delivered in a microexplosion of a tin droplet short-circuiting the tips of nichrome electrodes connected to a variac.

Before each experiment, the entire tube is evacuated to about 10^{-3} Torr. The driver section is filled with the desired C_2H_4/air mixture using the method of partial pressures. The test section is separated from the driver section by a large gate valve and filled with the same fuel/air ratio, plus the desired amount of gaseous fire fighting agent to maintain equal total pressures on both sides of the gate valve. After filling each portion of the tube the gases are homogenized separately using a two-sectional, spark-free circulating pump. Just prior to ignition, the gate valve is opened. The flame propagating in the driver section accelerates and generates shock waves ahead of it. After passing through the open gate valve the flame/shock wave encounters the same combustible mixture and a certain amount of agent. Depending on the concentration of the agent, the flame is decelerated and the pressure wave is attenuated. The speed and magnitude of the pressure wave are measured with piezo-electric pressure transducers, and the motion of the flame is monitored with photodiodes. Data are collected with a digital storage oscilloscope and data acquisition computer.

The gate valve arrangement is unique in high speed flame suppression studies, where traditionally the agent is premixed with the fuel and air, and the combination is ignited within a closed chamber. A major disadvantage of the premixed arrangement is that the results are strongly dependent on the ignition source and volume of the vessel, and that premixing does not duplicate the actual situation in a dry bay fire where the agent encounters an already established accelerating turbulent flame. Heinonen *et al.* (1991) avoided premixing by injecting the agent into a test chamber after igniting a fuel spray, but had difficulty repeating the ignition process.

Validation of Facility with Nitrogen

Preliminary experiments using 5% ethene in air mixtures have been run under a variety of conditions to validate the operation of the system. Figure 2 is an example of a pressure trace for the case of 10% N_2 at 100 kPa. Knowing the distance between the two pressure transducers, the shock speed can be determined from the time lag between the pressure rises. The pressure ratio can be tabulated from the initial pressure in the tube and either the first peak or the maximum pressure increase. The sensitivity of the flame speed and pressure ratio to the voltage of the ignition system, the mixing time of the components before ignition, the presence or absence of the gate valve, the speed of opening the gate valve, and cleaning the tube between runs have been investigated. The results have led to an experimental protocol which yields flame speeds which are reproducible from run to run within about $\pm 2\%$. Pressures downstream of the shockwave have a higher variability because of the complex shock structures created by interactions with the spiral rod insert.

Experiments were conducted with 100% nitrogen in the test section, a 5% ethene in air mixture in the driver section, and the total pressure equal to 20, 50 and 100 kPa. The incident shock wave velocity measured 2.2 m beyond the gate valve and 0.3 m from the end of the tube was 420 ± 8 m/s at all three total pressures. The pressure ratio based upon the initial pressure rise was 2.5 ± 0.5, and about 3.0 ± 1.0 based upon the peak increase.

As can be seen in Figure 3, no significant change in shock speed occurs until the volume per cent of nitrogen in air drops to 40%. The amount of nitrogen must be reduced to 30% to achieve a similar enhancement in velocity for the 20 kPa case. The pressure ratio based upon the initial rise is plotted in Figure 4. P_i/P_0 increases dramatically at the same point as the velocity, reaching maxima of 26 and 18, respectively, for the 20 kPa and 100 kPa initial conditions when no nitrogen is added to the ethene/air mixture.

Preliminary Results for CF_3Br

Experiments using halon 1301 (CF_3Br) were run to compare an inerting agent like nitrogen to a strong chemical inhibitor, and to determine the suitability of the facility for assessing the effectiveness of a wide range of agents for suppressing a high speed turbulent flame. Halogenated compounds, unlike nitrogen, are known to promote the production of soot. To determine the sensitivity of the Mach number to soot contamination, a series of experiments with 5% ethene/air mixtures at a total pressure of 20 kPa was run for CF_3Br partial pressure fractions between zero and 0.1 with and without cleaning the tube and spirals in the test section. The performance was similar with no particular trend discernible, with the maximum deviation between results amounting to less than 35 m/s.

Figure 5 shows the shock velocity measured at three different total pressures as a function of the partial pressure fraction of CF_3Br in the test section. Two observations can be made: first, the halon decelerates the shock speed at levels about one tenth the amount required for N_2; and, second, the largest effect of total pressure occurs between 50 and 100 kPa for the halon, compared to between 20 and 50 kPa for the nitrogen.

The pressure ratio across the shock based upon the initial rise is plotted in Figure 6. As for nitrogen, P_1/P_o increases significantly at the same point as the velocity, reaching the respective maxima.

Conclusion

A 5% ethene/air mixture which is ignited within a 7.5 m long, 50 mm diameter tube has been demonstrated to produce a pressure wave velocity of 800 to 1200 m/s as the total system pressure is raised from 20 to 100 kPa. The test section, initially separated from the driver section by a 50 mm diameter gate valve, can be used to evaluate the relative ability of different gaseous suppressants to decelerate the flame front and attenuate the pressure rise across the incident shock wave. Initial experiments with N_2 and CF_3Br as the suppressants indicate that the facility is flexible, and that the resulting wave velocities and pressure ratios are likely to be reproducible to the degree necessary to discriminate among the performance of alternative gaseous fire fighting agents.

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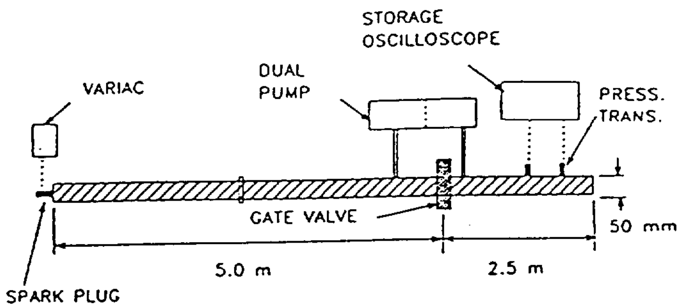

Fig. 1. Schematic of high speed flame facility.

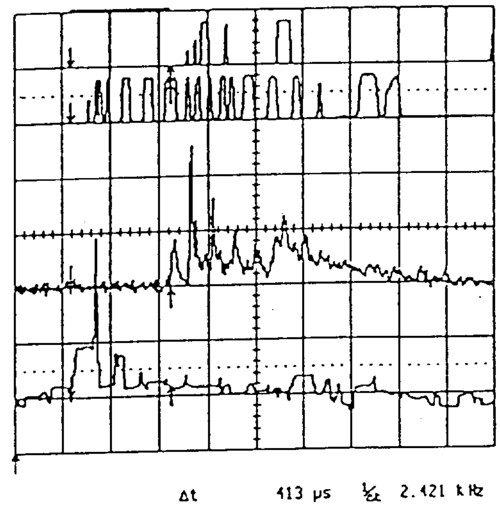

Fig. 2. Pressure trace in high speed turbulent flame.

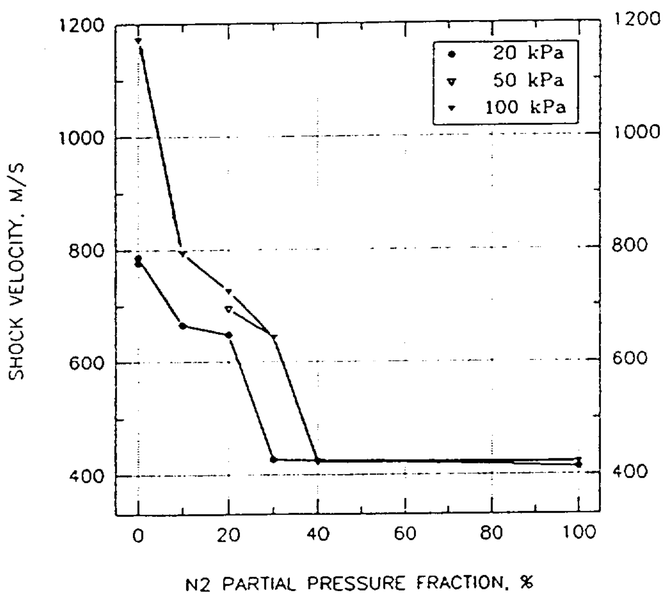

Fig. 3. Wave speed in N_2-suppressed C_2H_4/air.

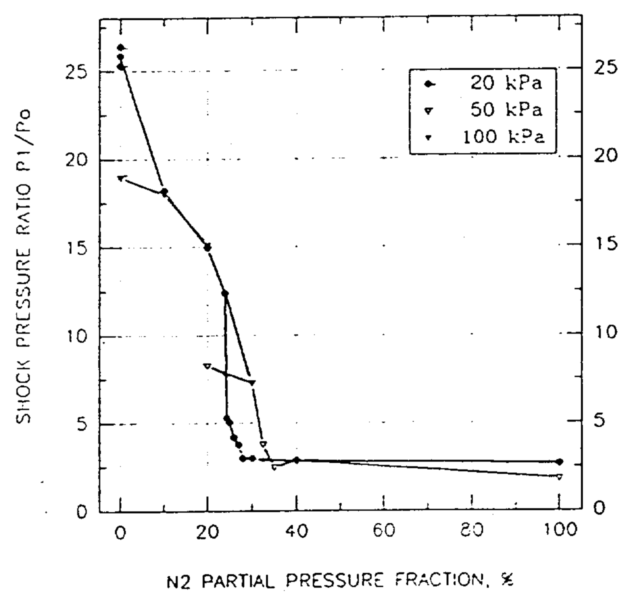

Fig. 4. Pressure ratio in N_2-suppressed C_2H_4/air.

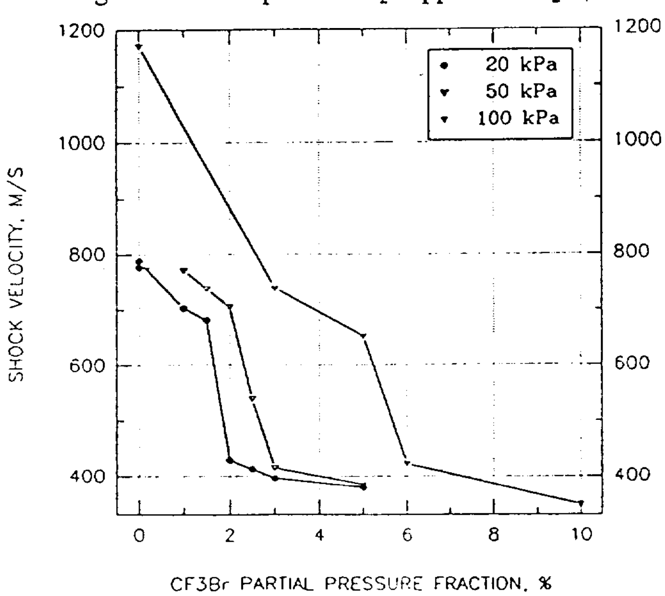

Fig. 5. Wave speed in CF_3Br-suppressed C_2H_4/air.

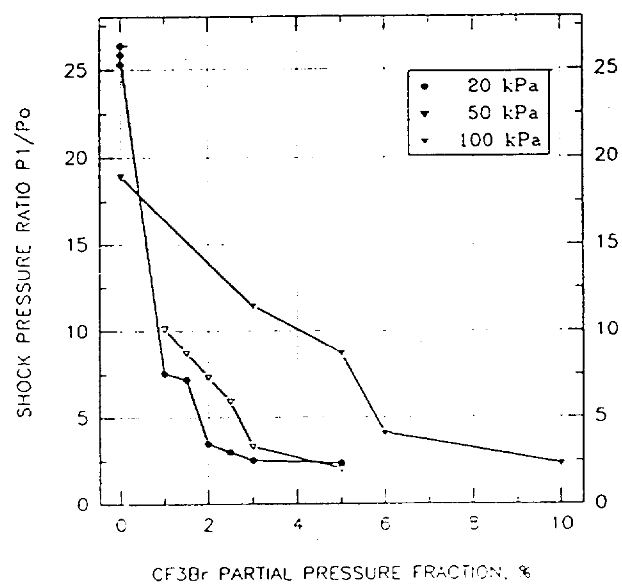

Fig. 6. Pressure ratio in CF_3Br-suppressed C_2H_4/air.